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Comparison of Mechanical Properties of Polymer-Based Multi-Phase Particulate Composites

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14. ABSTRACT

Multi-constituent particulate composites consist of individual particles of more than one material dispersed throughout and held together by a polymer binder. The mechanical and physical properties of the composite depend on the mechanical and physical properties of the individual components, particularly the binder; their loading density; the shape and size of the particles; the interfacial adhesion; residual stresses; and matrix porosity. Multi-constituent composites with cast-cure epoxy binder have been presented recently. In this study, the microstructure is varied by injection molding PMMA-based composites. The dynamic mechanical properties of PMMA-based and epoxy-based composites are measured using a split Hopkinson pressure bar. The mechanical properties of these composites are compared.

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Abstract
Multi-constituent particulate composites consist of individual particles of more than one material dispersed throughout and held together by a polymer binder. The mechanical and physical properties of the composite depend on the mechanical and physical properties of the individual components, particularly the binder; their loading density; the shape and size of the particles; the interfacial adhesion; residual stresses; and matrix porosity. Multi-constituent composites with cast-cure epoxy binder have been presented recently. In this study, the microstructure is varied by injection molding PMMA-based composites. The dynamic mechanical properties of PMMA-based and epoxy-based composites are measured using a split Hopkinson pressure bar. The mechanical properties of these composites are compared.

Introduction
Polymer composites comprised of metallic particles distributed throughout a contiguous polymer matrix can often be modified to produce advanced composites that exhibit multifunctional characteristics. For example, epoxy with Ni and Al particles [1,2] to produce high strength materials with exothermic reactive properties, or Teflon® (PTFE) can be reinforced with Al and W particles [3]. The properties of the particulate composites often depend on varying particle size, loading fractions, particle type, and the adhesion between the particulate and the matrix [2-6].

Several studies on epoxy-based composites with similar microstructures have been reported. These studies have shown that particle size [3, 7-9], shape [10], and concentration [11] and properties of the constituents can affect mechanical properties. In Al_2O_3 particle-filled epoxy (Epon 828/Z), increasing the particle concentration and decreasing the particle size is found to increase the stress corresponding to 4% plastic strain [12]. A study of aluminum particle filled epoxy (DGEBA/MTHPA) composites has found that a small amount of filler (~ 5 vol.%) increases the compressive yield stress, but additional amounts of filler decrease the compressive yield stress [13]. However, tests on glass-bead-filled epoxy (DOW DER 331/bisphenol-A) found that increasing the volume fraction increased both the yield stress and fracture toughness of the material [14,15]. In another study on a similar material, decreasing the aluminum particle size from micro to nano resulted in increased epoxy crosslink density and subsequently increased both static and dynamic strength [2].

This paper will present the experimental results comparing aluminum and nickel particles in PMMA prepared by injection molding with the same particles in epoxy prepared in a cast-cure process.

Experimental Approach
The samples for this study were prepared using a factorial design of experiments approach in order to maximize the number of variables tested with the minimum number of test specimens. The variables tested were aluminum particle size (5, 30 or 50 μm), volume percent of aluminum (20, 30, 40 vol.%), and the volume percent nickel (0, 5, 10 vol.%). Two levels and a centerpoint were chosen for the samples. The binder was a thermoplastic, PMMA. These samples compare directly with the epoxy-based samples discussed in previous papers [1, 16], with the exception that the PMMA based samples added a centerpoint to test for curvature. Table 1 shows the details of the factorial design for the PMMA-based samples; the epoxy-based samples are numbered the same starting with MNML and excluding the centerpoint.

Dynamic compression experiments were conducted using a split Hopkinson pressure bar (SHPB) [17] system at a strain rate of approximately 5000 /s. The bar system is comprised of 1524 mm long, 12.7 mm diameter incident and transmitted bars of 6061-T6 aluminum. The striker is 610 mm long and made of the same material as the other bars. The samples, which were nominally 5 mm diameter by 2.5 mm thick, are positioned between the incident and transmitted bars. The bar faces were lightly lubricated with grease to reduce friction. A complete description of this testing system can be found in Reference 17.

Table 1: Material configurations from a two-level, three factor design of experiments including a centerpoint

Material	Al Particle Size (μm)	Al Volume Fraction (%)	Ni Volume Fraction (%)
RXRW-1	50	40	10
RXRW-2	5	40	10
RXRW-3	50	20	10
RXRW-4	5	20	10
RXRW-5	50	40	0
RXRW-6	5	40	0
RXRW-7	50	20	0
RXRW-8	5	20	0
RXRW-9	30	30	5

Results and Discussion

Both sets of samples, PMMA-based and Epoxy-based, were tested in compression at 5000 /s. Figure 1 shows representative curves from the both materials containing 20 vol.% of 5 μm Al and 10 vol.% Ni. The compressive response of these materials is very different. The epoxy-based composite shows a rise to a peak stress, followed by a small decrease, a region of perfect plasticity and then work hardening, similar to other epoxy-based composites [18]. This is consistent with the deformation of the epoxy binder [17] with the strain softening after the peak decreased potentially due to particle-particle interaction. In contrast, the PMMA-based material shows a rapid rise to a peak stress, followed by a rapid strain softening, and then perfect plasticity at a very low stress. This is consistent with behavior of particulate composites that fail at the peak stress, where the low residual stress is the loading of sample fragments [19].

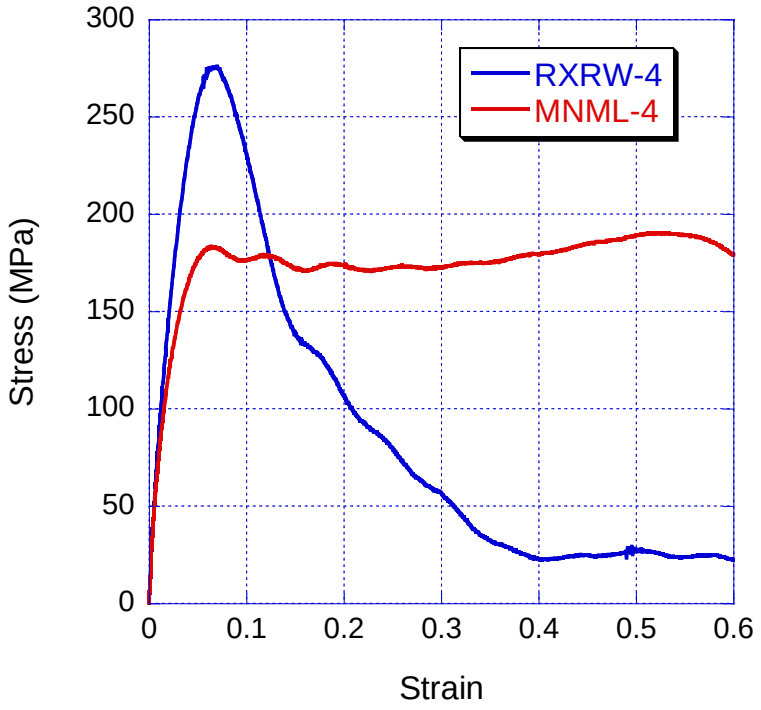

Figure 1: Stress-strain response of RXRW-4, PMMA-Al-Ni, and MNML-4, Epoxy-Al-Ni, at a strain rate of 5000 /s.

The peak stress from both the PMMA-based and epoxy-based samples are plotted versus the total volume fraction of particles in Figure 2. The open symbols are the small aluminum samples and the closed symbols are the large aluminum samples. Additional data from the epoxy-based samples at the same strain rate and a slightly lower strain rate are included for comparsion [1]. The trend lines are included to guide the eye rather than as linear fits to the data. There is good agreement between the previously acquired epoxy-based data [1] and that measured in this study. The strengths of the binder materials are included for comparison. For both materials, the small aluminum samples generally have a higher strength than the large aluminum samples. For the epoxy-based, the strength of the composites increases with increasing volume fraction of

particles. For the PMMA-based composites, the strength of the composites decreases with increase in volume fraction of particles. This decrease is believed to be due to the failure of the samples at the peak stress, which could be caused at lower stresses with a higher fraction of particles. These samples were loaded to 50 vol.% total particles. It is interesting that at this point, both the PMMA-based materials and epoxy-based materials seem to be converging to a common peak stress. This stress may be similar to that for a collection of particles as the particle-particle interaction begins to dominate the stress-strain response of the composites, irrespective of the particular polymeric binder used.

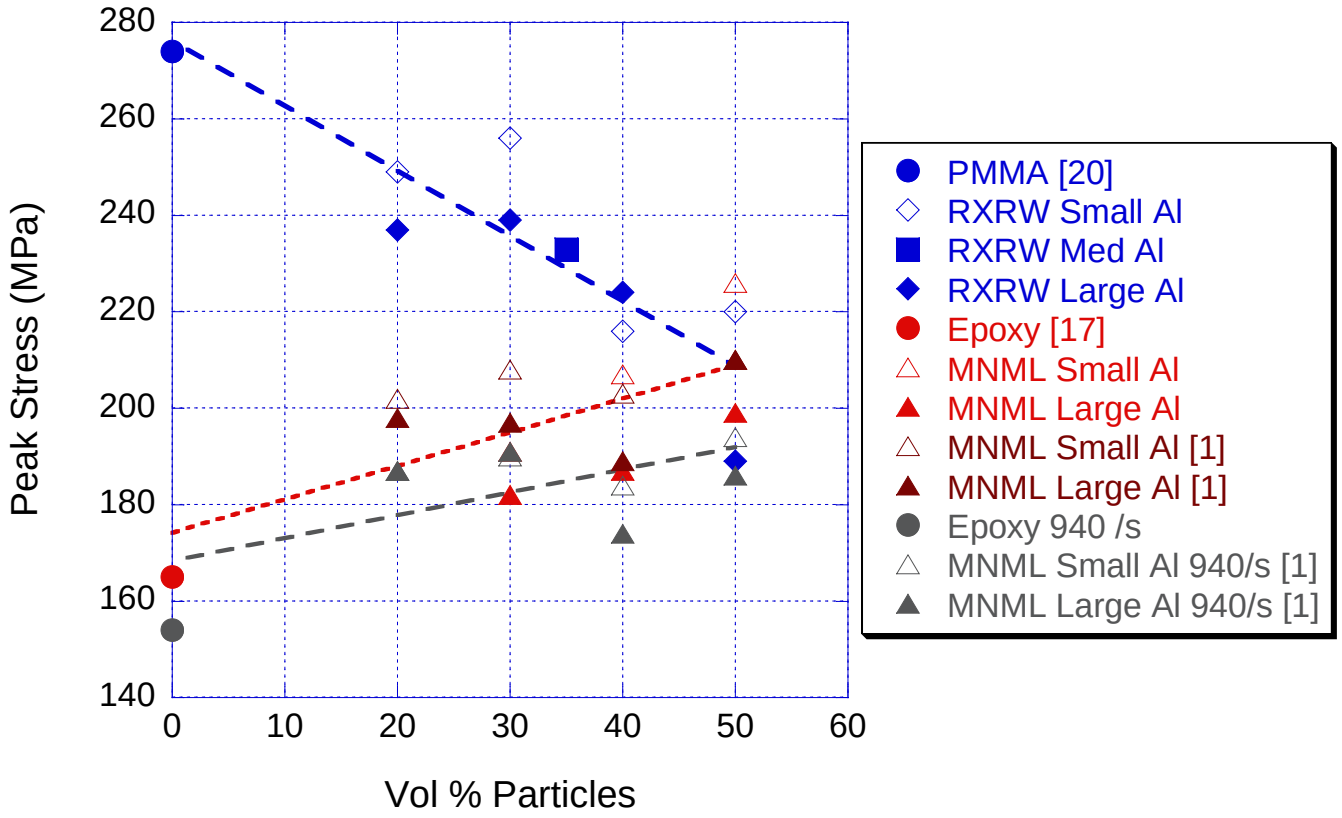

Figure 2: Volume fraction of particles versus peak stress measured using a split Hopkinson pressure bar for RXRW samples (PMMA-Al-Ni) and MNML samples (Epoxy-Al-Ni) where the experimental strain rate is 5000 /s. Open symbols represent samples that contain 5 μm aluminum and closed symbols represent samples with 50 μm aluminum.

Summary

Multi-constituent particulate composites consist of individual particles of more than one material dispersed throughout and held together by a polymer binder. The mechanical and physical properties of the composite depend on the mechanical and physical properties of the individual components, particularly the binder; their loading density; the shape and size of the particles; the interfacial adhesion; residual stresses; and matrix porosity. Multi-constituent composites with cast-cure epoxy binder have been presented recently. In this study, the microstructure is varied by injection molding PMMA-based composites. The dynamic mechanical properties of PMMA-based and epoxy-based composites are measured using a split Hopkinson pressure bar. The PMMA-based materials show a rise to peak stress followed by a sharp strain softening, indicating failure of the samples. In contrast, the epoxy-based samples show a nearly perfectly-plastic stress after a rise to peak stress.

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Opinions, interpretations, conclusions and recommendations are those of the authors and are not necessarily endorsed by the United States Air Force.

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